2012 IEEE International Conference on Power Electronics, Drives and Energy Systems
December16-19, 2012, Bengaluru, India

Energy Efficiency Improvement of Auxiliary Power Equipment in Thermal Power Plant through Operational Optimization

Mr. Rajashekar P. Mandi
Energy Conservation & Development Division,
Central Power Research Institute, Bangalore, India
e-mail:mandi@cpri.in

Dr. Udaykumar R. Yaragatti
Dept. of Electrical & Electronic Engineering
National Institute of Technology, Surathkal, India
e-mail : udaykumarry@yahoo.com

Abstract- **This paper describes the results of energy conservation measures for 210 MW coal fired power plant in various thermal power plants spread over the country. Energy efficiency improvement of major auxiliary equipment with different plant load factors are summarized here with improved performance. The effect of plant load factor on all major auxiliary equipment and suggestions for improving the performance of auxiliary equipment are discussed in this paper. Operation of the plant at improved plant load factor reduced the auxiliary power from 12.05 % at 70 % PLF to 8.74 % at 100 % PLF that reduced the net auxiliary power by 9.1 MU/year and CO_2 emission is reduced by about 9,500 t/year. Operating the plant at optimum excess air, controlling the furnace ingress, improving the performance of individual equipment by proper maintenance, etc., improved the plant capacity and reduced the overall auxiliary power by about 1.5 – 2.1 % of gross energy generation.**

Keywords- Auxiliary power, plant load factor, energy efficiency, energy conservation, specific energy consumption

I. INTRODUCTION

The present total installed power generation capacity in India is 182.7 GW, out of which 100 GW is from coal based thermal power plant that forms 54.8 % of total installed capacity Dec. 2011 [1]. The auxiliary power used for coal fired power plants is varied for different plant size from 30 MW plant to 500 MW plants, varied between 5.2 % and 12.3 %. The estimated auxiliary power used for running the coal fired power plants in India is about 8400 MW that forms about 8.4 % of coal based power plants & 4.6 % of total installed capacity [2]. The thermal power plant availability depends largely upon the operational reliability of the auxiliary equipment and the capability of the auxiliary system [3]. The net overall efficiency of the coal fired thermal power plants are in the range of 19.23 % (30 MW plant) and 30.69 % (500 MW plant). The auxiliary power consumption is varying between 5.2 % (500 MW plant) and 12.3 % (30 MW plant).The auxiliary power consumption is on higher side as compared to other developed countries [4] due to poor plant load factor, the use of poor coal quality, excessive steam flow, excessive water flow, internal leakage in equipment, inefficient drives, lack of operational optimization of equipment, ageing of equipment, hesitation in technology upgradation, obsolete equipment, design deficiencies, oversizing of equipment, use of inefficient controls, etc., If the auxiliary power of coal fired stations in India is improved by 1 %, about 1000 MW of power can be pumped into grid with nominal investment for plant performance improvement.

At presently in India due to introduction of Availability Based Tariff (ABT) for the generators to pump the power into grid, many of the power generators are asked to back down of their plants and to operate at partial load. This is causing the drop in plant load factor. On the other hand, due to restriction in some of the equipments, the units are running at sub-optimal plant load which cause reduced plant load factor of unit. In order to get better energy efficiency of auxiliary equipment, it is essential to run the plant at its full capacity. Thus, operational optimization of thermal power units will help in improving the energy efficiency of auxiliary equipment and reduce the energy consumption substantially. Figure 1 gives the schematic of the major auxiliary equipment in 210 MW coal fired power plants.

The auxiliary power consumption can be reduced, by improving the plant load factor of the plants, by operational optimization, adoption of advanced control techniques and implementation of energy conservation measures. By reducing the auxiliary power additional power will be available at grid.

This paper presents the results of performance test conducted on 23 units of 210 MW sub-bituminous coal fired power plants with tangentially corner fired and balanced draft system.

II. AUXILIARY POWER CONSUMPTION

The auxiliary power is the essential power used by the auxiliary equipment. The auxiliary power is tapped at Unit Auxiliary Transformers (UAT) during normal running of the plant and from Station Transformers (ST) during starting of the plant. The auxiliary power can be broadly classified into in-house auxiliary power whose loading vary with change in plant load of particular unit and out-lying or common auxiliary power. The typical in-house auxiliary equipment are: Boiler feed pumps (BFP), Condensate Extraction pumps (CEP), Induced draft fans

978-1-4673-4508-8/12/$31.00 ©2012 IEEE

(ID), Forced draft fans (FD), Primary air fans (PA), Mills, etc. The typical out-lying auxiliary equipment are: Circulating water pumps (CWP), Ash slurry pumps, HP & LP water pumps, DM pumps, Crushers, Conveyors, Wagon tipplers, etc.

The major in-house auxiliary power equipment are:

1. Boiler feed pumps are multi stage pumps that increase the feed water pressure from deaerator (i.e., about 5 – 6 kg_f/cm^2 to 160 – 175 kg_f/cm^2) to drum pressure. The motor rating for 210 MW will be of either 4.0 MW or 3.5 MW of 6.6 kV. Out of three pumps, two pumps will be working continuously and third will be stand-by. The feed water flow is regulated by scoop (fluid coupling) control and 3 element feed control valve station. The auxiliary power used by BFP accounts for 2.46 % of gross energy generation at 100 % Maximum Continuous Rating (MCR) or designed plant load as against to the design value of 2.28 %.
2. Condensate extraction pumps are centrifugal pumps with HT induction motor of 6.6 kV. Generally two pumps of 500 kW or three pumps of 250 kW are installed, one pump (for 500 kW) or two pumps (for 250 kW) will be working continuously and other will be stand-by. The condensate flow will be regulated by throttle valve. The auxiliary power used by CEP accounts for 0.23 % of gross energy generation at MCR as against to the design value of 0.22 %.
3. Induced draft fans are of radial fans with HT induction motor of 6.6 kV. Generally two fans of either 1250 kW or 1500 kW are installed and both will be working continuously to maintain the furnace pressure to -5 to -10 mmWCL and throw out the flue gas to atmosphere through chimney. The flue gas flow will be regulated generally by Inlet Guide Vane (IGV) and Scoop control. The auxiliary power used by ID fans account for 1.12 % of gross energy generation at MCR as against to the design value of 0.90 %.
4. Forced Draft fans are generally of axial reaction type fans with HT induction motor of 6.6 kV. Generally two fans of 650 kW or 750 kW or 850 kW are installed and both will be working continuously to provide the secondary air for combustion at windbox and to maintain the windbox differential pressure to about 100 mmWCL. The secondary air flow is regulated by operating pitch of FD fan blades. The auxiliary power used by FD fans account for 0.23 % of gross energy generation at MCR is lower compared to the design value of 0.25 %.
5. Primary air fans are of radial fans with HT induction motor of 6.6 kV. Generally two fans of either 1100 kW or 1250 kW are installed and both will be working continuously to provide the primary air of about 700 – 800 mmWCL at mill inlet to lift the pulverized coal from mills to burners. The primary air flow is regulated generally by IGV. The auxiliary power used by PA fans account for 0.92 % of gross energy generation at MCR as against to the design value of 0.65 %.
6. In a 210 MW power plant six numbers of XRP 863 Bowl mills are installed. According to the Original design of the plant, four mills have to be working continuously, one mill will be hot stand-by and another mill will be cold stand-by. But due to use of inferior coal quality, now a day five mills are being used continuously and sixth mill will be stand-by. The auxiliary power used by Mills accounts for 0.66 % of gross energy generation at MCR as against to the design value of 0.50 %.

Figure 1 gives the schematic of the in-house major auxiliary equipment in a typical coal fired power plants.

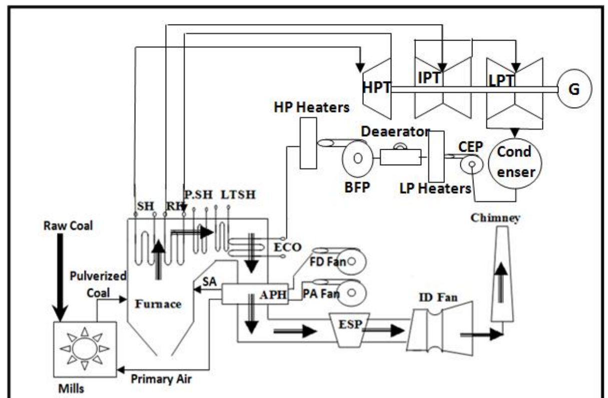

Figure 1: Schematic of thermal power plant

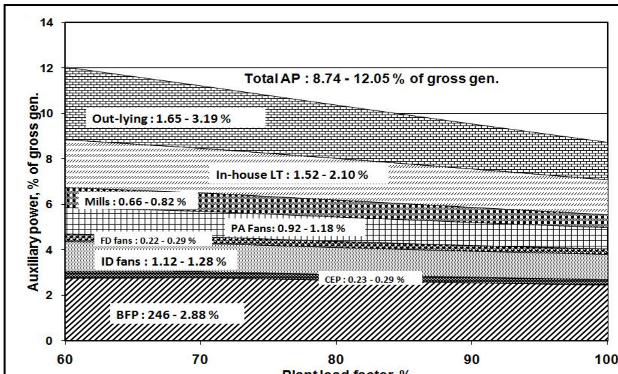

Figure 2. Auxiliary power of individual equipment

Figure 2 gives the share of Auxiliary power for different individual equipment. The auxiliary power is greatly influenced by the Load Factor (LF) of units. It can be seen from the Figure that as the load factor increases, the percentage of auxiliary power decreases. The total auxiliary power is curve fitted to:

$$AP = 5*10^{-5}*LF^2 - 0.0893*LF + 17.228 \quad \% \quad (1)$$

Where AP is the total auxiliary power in percentage of gross power generation and LF is load factor of unit in percentage and is computed as:

$$LF = \frac{P_{Gen}}{P_{Rating}} * 100 \quad \% \qquad (2)$$

Where P_{Gen} is the average power generation by the individual generator in MW, P_{Rating} is the Maximum Continuous Rating (MCR) of particular generator in MW.

III. PLANT LOAD FACTOR

The auxiliary power is greatly influenced by the plant load factor. Many of the Indian power stations are operating at sub-optimal plant load factor that cause higher auxiliary power and increase the pollution

As per the plant performance reports published by ICRA, 2003 [5], MECON Ltd. report for MSPGCL plants, 2007 [6], RTPS, 2008 [7], DVC, 2005 [8], the percentage of auxiliary power vary with PLF.

The annual plant load factor is generally computed by

$$PLF = \frac{E_{Gen} * 100}{P_{Rating} * 8760 * 1000} \quad \% \qquad (3)$$

Where E_{Gen} is actual energy generated in MU/year and P_{Rating} is the rated capacity of plant in MW.

The instantaneous plant load factor is computed by

$$PLF = \frac{P_{Gen} * 100}{P_{Rating}} \quad \% \qquad (4)$$

The deviation between actual operating value at partial plant load to operating value at MCR (i.e., 210 MW considered as 100 % plant load) is computed as:

$$Deviation = \frac{\left(V_{MCR} - V_{Partial}\right) * 100}{V_{MCR}} \quad \% \qquad (5)$$

Where V_{MCR} is the operating value at MCR condition (i.e., 100 % plant load 210 MW) and $V_{Partial}$ is the operating value at partial plant load.

The Boiler output is directly proportional to FW flow & pressure, air flow & pressure and coal flow. Therefore, the increase in Boiler output will increase the auxiliary power of BFP, CEP, ID fans, FD fans, PA fans, and Mills.

The turbine output is directly proportional to steam flow, pressure & enthalpy and condenser vacuum. The main steam pressure & flow are depending on the FW flow & pressure. The condenser vacuum is dependent on the circulating water temperature & flow at condenser inlet. Therefore, the increase in turbine output will increase the auxiliary power of BFP, CEP, CWP, etc.

The plant load factor of the units will be lower due to following reasons:

a) Poor coal quality: high ash coal reduce the capacity of mills, steaming rate, overloading of ID fans, ESPs, etc [9].
b) Poor performance of ESPs: This will overload the ID fans that cause hurdle in maintaining the furnace pressure negative
c) Erosion of ID fan impellers: Reduce the capacity of ID fans and will not be able to maintain the furnace pressure [10].
d) Poor condenser vacuum: reduce the loadability of turbine
e) Inadequate circulating water temperature at condenser: reduce the vacuum at condenser.
f) Air leakage in APH: Overloading of ID fans, FD fans & PA fans.
g) Higher flue gas pressure drop across APH, ESP, Economizer, ducts, etc: Reduce the capacity of ID fans
h) Inadequate primary air supply: Reduce the capacity of pulverized coal lifting from mill to burners
i) Non-availability of Mills, PA fans, etc.
j) Restriction in auxiliary equipment like BFP, CEP, Mills, PA fans, FD fans, ID fans, etc
k) Inadequate coal supply
l) Less demand in grid

The reduced plant load factor reduces the power output at generator terminal which in turn reduces fluid flow in all major equipments i.e., steam flow, FW flow, Condensate flow, Flue gas flow, SA flow, PA flow and coal flow.

The variation of fluid flows of all major equipments with plant load factor are curve fitted to:

$$Fluid\ flow = A_0 + A_1 * PLF + A_2 * PLF^2 \quad t/h \qquad (6)$$

Where A_0, A_1 and A_2 coefficients and are given in Table 1 for all major auxiliary equipments

TABLE 1. CURVE FIT VALUES OF FLOW WITH PLF (X-AXIS: PLANT LOAD FACTOR (RANGE: 70 % TO 100 %)) AT 210 MW PLANT.

Sl. No.	Equip-ment	Y-axis	A_0	A_1	A_2
01	BFP	Feed water flow	-902.78	29.22	-0.1319
02	CEP	Condensate flow	502.23	-0.4.0665	0.0342
03	ID fans	Flue gas flow	-406.01	1.039	-0.0569
04	FD fans	Secondary air flow	600.39	-5.359	0.0387
05	PA fans	Primary air flow	4.9971	4.545	-0.0141
06	Mills	Coal flow	-197.34	6.255	-0.0294

The deviation in fluid flow is computed as:

$$Deviation\ \ in\ Fluid\ \ flow = \frac{\left(\overset{o}{m}_{rated} - \overset{o}{m}_{operating}\right)*100}{\overset{o}{m}_{rated}} \% \quad (7)$$

Where $\overset{o}{m}_{\text{rated}}$ is the measured operating fluid flow i.e., feed water flow for BFP, condensate flow for CEP, primary air flow for PA fans, secondary air flow for FD fans, flue gas flow for ID fans, coal flow for Mills, at rated load (i.e. 210 MW) in t/h and $\overset{o}{m}_{\text{operating}}$ is the Fluid flow at different plant load factor in t/h.

The variation of deviation in fluid flow with plant load factor is curve fitted to:

$$Deviation\ in\ Fluid\ \ flow = B_0 + B_1 * PLF + B_2 * PLF^2 \% \quad (8)$$

Where B_0, B_1 and B_2 coefficients and are given in Table 2 for all major auxiliary equipments

TABLE 2. CURVE FIT VALUES OF DEVIATION IN FLUID FLOW WITH PLF (X-AXIS: PLANT LOAD FACTOR (RANGE: 70 % TO 100 %)) AT 210 MW PLANT.

Sl. No.	**Equip-ment**	**Y-axis**	**B_0**	**B_1**	**B_2**
01	BFP	Deviation of FW flow	-226.79	4.1039	-0.0189
02	CEP	Deviation of Condensate flow	14.143	-0.9242	0.0078
03	ID fans	Deviation of Flue gas flow	-63.422	0.0936	0.0051
04	FD fans	Deviation of Secondary air flow	32.244	-1.1804	0.0085
05	PA fans	Deviation of Primary air flow	-98.458	1.4028	-0.0044
06	Mills	Deviation of Coal flow	-244.05	4.5657	-0.0215

The auxiliary power of individual equipment is computed by

$$AP_{Equipment} = \frac{P_{Equipment} * 100}{PL * 1000} \% \quad (9)$$

Where $AP_{Equipment}$ is the auxiliary power of individual equipment in percentage of gross generation, $P_{Equipment}$ is the power input to motor in kW and PL is the measured plant load (or gross generation of unit) in MW.

The variation of electrical power input to all major equipments with plant load factor are curve fitted to:

$$AP_{Equipment} = C_0 + C_1 * PLF + C_2 * PLF^2 \% \quad (10)$$

Where C_0, C_1 and C_2 coefficients and are given in Table 3 for all major auxiliary equipments

TABLE 3. CURVE FIT VALUES OF AUXILIARY POWER AT INPUT WITH PLF (X-AXIS: PLANT LOAD FACTOR (RANGE: 70 % TO 100 %)) AT 210 MW PLANT.

Sl. No.	**Equip-ment**	**Y-axis**	**C_0**	**C_1**	**C_2**
01	BFP	AP of BFP	4.2866	-0.0243	6×10^{-5}
02	CEP	AP of CEP	0.8106	-0.0109	5×10^{-5}
03	ID fans	AP of ID Fans	2.2894	-0.0207	9×10^{-5}
04	FD fans	AP of FD fans	0.7451	-0.0093	4×10^{-5}
05	PA fans	AP of PA fans	0.9818	+0.0109	-1.154×10^{-4}
06	Mills	AP of Mills	1.5011	-0.0131	-4.7×10^{-5}

The deviation in auxiliary power for equipment is computed at different plant load factors.

$$Deviation\ \ in\ AP_{Equipment} = \frac{\left(AP_{rated} - AP_{operating}\right)*100}{AP_{rated}} \% \quad (11)$$

Where AP_{rated} is the rated power of equipment in kW, $AP_{operating}$ is the actual operating power input to equipment in kW.

The variation of deviation in auxiliary power of individual equipment with plant load factor is curve fitted to:

$$Deviation\ in\ AP_{Equipment} = D_0 + D_1 * PLF + D_2 * PLF^2 \% \quad (12)$$

Where D_0, D_1 and D_2 coefficients and are given in Table 4 for all major auxiliary equipments

TABLE 4. CURVE FIT VALUES OF DEVIATION IN POWER INPUT WITH PLF (X-AXIS: PLANT LOAD FACTOR (RANGE: 70 % TO 100 %)) AT 210 MW PLANT.

Sl. No.	**Equip-ment**	**Y-axis**	**D_0**	**D_1**	**D_2**
01	BFP	Deviation of BFP power	71.637	-0.9783	0.0026
02	CEP	Deviation of CEP power	78.986	-0.9724	0.0019
03	ID fans	Deviation of ID fan power	89.09	-1.3026	0.0043
04	FD fans	Deviation of FD fan power	220.74	-3.5823	0.0139
05	PA fans	Deviation of PA fan power	19.605	0.6628	-0.0085
06	Mills	Deviation of Mill power	91.644	-0.0842	-0.0082

But the energy indices increase at lower plant load factor:

a) Specific steam consumption (SSC): ratio between steam flow in t/h to generator output in MW

b) Specific fuel consumption (SFC) : ratio between coal consumption in t/h to generator output in MW
c) Specific energy consumption (SEC): ratio between electrical power in kW to FW flow or condensate flow or air flow or coal flow or flue gas flow in t/h at individual equipment

The energy indices i.e., Specific Energy Consumption (SEC) for individual equipment is computed as:

$$SEC_{Equipment} = \frac{P_{Equipment}}{Fluid\ flow} \quad kW/t\ of\ fluid \tag{13}$$

The variation of SEC of all major equipments with plant load factor are curve fitted to:

$$SEC_{Equipment} = E_0 + E_1 * PLF + E_2 * PLF^2 \quad \% \tag{14}$$

Where E_0, E_1 and E_2 coefficients and are given in Table 5 for all major auxiliary equipments

TABLE 5. CURVE FIT VALUES OF SEC WITH PLF (X-AXIS: PLANT LOAD FACTOR (RANGE: 70 % TO 100 %)) AT 210 MW PLANT.

Sl. No.	Equip-ment	Y-axis	E_0	E_1	E_2
01	BFP	SEC of BFP	24.274	-0.3562	0.0019
02	CEP	SEC of CEP	1.3940	-0.0040	8×10^{-6}
03	ID fans	SEC of ID Fans	3.6832	-0.0215	6×10^{-5}
04	FD fans	SEC of FD fans	0.7315	0.0090	-6×10^{-5}
05	PA fans	SEC of PA fans	2.7955	0.1128	-0.0008
06	Mills	SEC of Mills	39.636	-0.6122	0.0032

IV. ENERGY CONSERVATION MEASURES TO IMPROVE PLF

The major constraint in raising the plant load is healthiness and capacity adequacy of all the major auxiliary equipment especially Mills and ID fans. Mills are major equipment that provides the coal to burners for combustion and ID fans suck the flue gas from furnace to maintain negative furnace pressure and throw out the flue gas.

Some of the measures to improve the capacity factor of mills are:

a) At presently the coal quality is poor that contains the ash quantity of the order of 50 – 60 %. At higher ash content, the mill capacity is reduced [11]. Average mill power increased by about 6.2 % at ash content of 50 %. Table 6 gives the results of mill performance with beneficiating coal. Reduction of ash content from 52 % to 31 % had decreased the auxiliary power by 20.9 %.
b) Appropriate sizing of pulverized coal i.e., 70 % passing through 200 mesh (below 75 micron size). At higher fineness SEC of mills is high, the carbon particle escape the combustion zone faster and increase un-burnt carbon in fly ash. At poor fineness, the SEC of mills is low, the heavier particle will fall down before combustion and increase the un-burnt carbon in bottom ash. Periodic adjustment of rollers and classifier or use of dynamic classifiers instead of static classifiers at mill output will improve the combustion characteristics. The increasing fineness of pulverized coal from 70 % passing through 200 mesh to 80 % increases the mill power by 8 %.
c) Use of hi-chrome liner and wear plates in mills had reduced the erosion rate and improved the mill performance by about 2 – 5 % [12].
d) Use of hi-chrome bull-ring segments and rollers enhanced the life of rollers to 6000 hours and improved the mill performance by about 5 – 8 %.
e) Periodic purging of mills to clear the mill is enhanced the capacity of mills and reduced the auxiliary power of mills by about 5 – 10 %.
f) Initially the raw coal will be crushed in crushers and reduce the coal size to below 25 mm and this crushed coal is fed to mills. Generally the crushers are of hammer mill type and their SEC will be low compared to pulverizer mills. In many occasions, the raw coal size at mill inlet is higher than 25 mm and this cause higher power consumption by mills. Maintaining the raw coal size at mill inlet below 25 mm is enhanced the capacity of mills. Higher raw coal size (above 25 mm size) at mill inlet reduced the mill capacity drastically that increased the mill auxiliary power.

TABLE 6. PERFORMANCE RESULTS OF MILLS WITH BENEFICIATING COAL AT 210 MW PLANT.

Sl. No.	Particulars	Unit	Raw Coal	Washed Coal
01	Moisture	%	16.0	18.0
02	Ash content	%	52.0	31.0
03	Calorific value	kcal/kg	2800	4300
04	Total mill power	kW	1503.1	1189.5
05	Average Mill loading	%	89.5	71.2
06	Mill Differential Pressure	mmWC	351.0	224.0
07	Total coal flow	t/h	128.2	117.6
08	Coal air temperature	^oC	68.9	81.2
09	Primary air	t/h	285.9	231.5
10	Air to fuel ratio	-	2.23	1.97
11	SEC	kWh/t	11.72	10.11

Some of the measures to improve the capacity factor of ID fans are:

a) Use of higher calorific value and low ash content coal reduced the flue gas flow that enhanced the capacity of ID fans. Reducing the ash content of coal by beneficiating the coal reduced the ash content of coal from 52 % to 31 % (Table 7). This reduced ash content had decreased the auxiliary power of ID fans by 28.6 % and improved the ID fans efficiency from 39.68 % to 46.07 %.

TABLE 7. PERFORMANCE RESULTS OF ID FANS WITH BENEFICIATING COAL AT 210 MW PLANT.

Sl. No.	Particulars	Unit	Raw Coal	Washed Coal
01	Moisture	%	16.0	18.0
02	Ash content	%	52.0	31.0
03	Calorific value	kcal/kg	2800	4300
04	Flue gas flow	t/h	1080.5	965.6
05	Total ID fan power	kW	2641.5	1886.7
06	SEC	kWh/t	2.44	1.95
07	Furnace pressure		-5.6	-4.9
08	ID fan Suction pressure	mmWCL	-276.6	-255.7
09	ID fan discharge pressure	mmWCL	15.3	15.2
10	Flue gas temperature	^{o}C	151	147
11	IGV position	%	89.5	78.3
12	ID Fan Eff.	%	39.68	46.07

b) The main purpose of ID fans is to suck the flue gas from furnace and throw out to atmosphere via chimney. The flue gas had to pass through various heating elements which have created hydrodynamic resistance for flue gas path. Table 8 gives the performance results of ID fans before and after overhaul. Reducing the flue gas pressure drop across APH from 146.8 mmWCL to 128.4 mmWCL had decreased the auxiliary power of ID fans by 6.43 %. Similarly reducing the flue gas pressure across ESP from 55.3 mmWCL to 39.8 mmWCL had reduced the auxiliary power of ID fans by 6.17 %.
c) Reducing the furnace ingress and air ingress in flue gas ducts reduced the burden on ID fans.
d) Improving the dust extraction efficiency of Electrostatic Precipitators (ESP) reduced erosion rate of ID fan impellers and reduced the loading of ID fans.
e) The ammonia dosing of flue gas enhanced the collection efficiency of ESPs by about 10 % that reduced loading on ID fans and reduced the auxiliary power of ID fans by about 3 – 5 %.
f) Generally in a 210 MW power plant, regenerative rotary air pre-heaters (APH) are used to extract the heat from flue gas to heat the primary & secondary air. The APH consists of tri-sector, one for flue gas, one for secondary air and other for primary air. The primary & secondary air pressures are on higher side and try to escape to flue gas side without taking part in combustion (work) which is at negative pressure [13]. This caused air leakage through APH that had increased the flue gas flow and load the ID fans. The measurement of air leakage through APH is diagnosed by measuring Oxygen content (O_2) at APH inlet and outlet. This air leakage through APH increased the burden on ID fans. It can be seen from the Table 9 that the flue gas flow is reduced after overhaul (i.e., by replacing the APH seals) by %. The increased power due to air leakage through APH is decreased from 271.12 kW to 120.38 kW for the reduction of O_2 from 6.2 % to 4.6 % after overhaul at APH outlet. The envisaged power saving is 5.71 %. Similarly the increased power due to air leakage in flue gas duct is reduced from 177.24 kW to 33.09 kW for the reduction of O_2 from 7.8 % to 4.9 % after overhaul at ID outlet. The power saving due to reduction in air leakage in flue gas duct is 5.46 %.
g) Hard facing of ID fan impellers reduced the erosion rate that enhanced the capacity of ID fans.

TABLE 8. PERFORMANCE RESULTS OF ID FANS WITH BENEFICIATING COAL AT 210 MW PLANT.

Sl. No.	Particulars	Unit	Before Overhaul	After overhaul
01	ID fan Suction pressure	mmWCL	-276.6	-231.8
02	ID fan discharge pressure	mmWCL	15.3	15.2
03	Flue gas temperature	^{o}C	151	147
04	Flue gas flow	t/h	1080.5	965.6
05	Total ID fan power	kW	2641.5	1886.7
06	SEC	kWh/t	2.44	1.95
07	Pressure drop across APH	mmWCL	146.8	128.4
08	Increased power due to higher Pr. Drop across APH	kW	188.23	18.33
09	Power saving	kW (%)	169.89 (6.43 %)	
10	Pressure drop across APH	mmWCL	55.3	39.8
11	Increased power due to higher Pr. Drop across APH	kW	283.61	120.69
12	Power saving	kW (%)	162.92 (6.17 %)	

Some of the other measures to improve the plant load factor are:

a) Improving the Boiler efficiency by enhancing the heat extraction capacity of Boiler components like economizer, water walls, super heaters, re-heaters, etc.
b) Enhancing the turbine efficiency by improving the turbine inlet and exit conditions, improving the condenser vacuum by maintaining the circulating water temperature near to design value through maintaining the cooling towers in good conditions [14].
c) Maintaining all the re-generative feed heaters (HP & LP heaters) in good condition will enhance the plant load.

d) Use of higher calorific value and low ash content coal will reduce the flue gas flow that enhance the capacity of ID fans.
e) Maintaining the generator stator winding and generator transformer winding temperature on lower side by enhancing the cooling system will help in increasing the plant load factor.
f) Reducing the Specific steam consumption (SSC) will enhance the capacity of BFP & CEP.
g) Reducing the Specific fuel consumption (SFC) will enhance the capacity of Mills, ID fans, FD fans and PA fans

TABLE 9. PERFORMANCE RESULTS OF ID FANS WITH BENEFICIATING COAL AT 210 MW PLANT.

Sl. No.	**Particulars**	**Unit**	**Before Overhaul**	**After overhaul**
01	Oxygen at Before APH	%	3.8	3.5
02	Oxygen at After APH	%	6.2	4.6
03	Oxygen at ID outlet	%	7.8	4.9
04	Flue gas flow	t/h	1080.5	786.8
05	Air leakage through APH	t/h	110.9	50.2
06	Air leakage tin ducts	t/h	72.5	13.8
07	Total ID fan power	kW	2641.5	1886.7
08	SEC	kWh/t	2.44	2.40
09	Increased power due to air leakage through APH	kW	271.12	120.38
10	Power saving	kW	150.74	
11	Increased power due to air leakage in duct	kW	177.24	33.09
12	Power saving	kW	144.15	

V. CONCLUSIONS

Operating the plant at improved plant load factor of 100 % MCR condition from 70 % PLF had reduced the total auxiliary power from 12.05 % to 8.74 % (Table 10) that reduced the overall auxiliary power by 9.1 MU/year and reduction of about 9,500 t/year of CO_2 is envisaged. The specific energy consumption of equipment had also decreased (Table 11). The use of washed coal will improved the performance of auxiliary equipment and reduced the auxiliary power by about 0.5 – 0.6 % of gross energy generation. Reducing the hydrodynamic resistance in flue gas circuit reduced the auxiliary power by about 0.4 – 0.5 % of gross energy generation. Operating the plant at optimum excess air, controlling the furnace ingress, improving the performance of individual equipment by proper maintenance, etc., reduced the auxiliary power by about 0.2 – 0.3 % of gross energy generation. The overall reduction of auxiliary power by operating the plant at optimum energy efficiency is about 1.5 – 2.1 %.

TABLE 10. RANGE OF AUXILIARY POWER OF MAJOR EQUIPMENT AT 210 MW PLANT.

Equipment	**Design AP, % of gross gen.**		**Operating AP, % of gross gen.**	
	70 % PLF	**100 % PLF**	**70 % PLF**	**100 % PLF**
BFP	2.70	2.28	2.88	2.46
CEP	0.25	0.22	0.29	0.23
ID fans	1.09	0.90	1.28	1.12
FD fans	0.28	0.25	0.29	0.22
PA fans	0.83	0.65	1.18	0.92
Mills	0.73	0.50	0.82	0.66
Total AP	**10.15**	**8.50**	**12.05**	**8.74**

TABLE 11. CURVE FIT VALUES OF SEC OF MAJOR AUXILIARY EQUIPMENT (X-AXIS: PLANT LOAD FACTOR) AT 210 MW PLANT.

Sl. No.	**Y-axis**	**Value at 70 % PLF, kW/t**	**Value at 100 % PLF, kW/t**
01	BFP	8.65	7.65
02	CEP	1.15	1.07
03	ID fans	2.47	2.13
04	FD fans	1.07	1.03
05	PA fans	6.77	6.08
06	Mills	12.46	10.42

ACKNOWLEDGEMENT

The authors are thankful to the management of CPRI, Bangalore and NITK, Surathkal to giving the opportunity to carry out the work and to publish this paper.

REFERENCES

[1] CEA, 2008, *Performance Review of Thermal Power Stations 2006-07*, website: http//:www.cea.nic.in.

[2] M. Siddhartha Bhatt and R.P. Mandi, "Performance enhancement in coal fired thermal power plants, part III: Auxiliary power", *International Journal of Energy Research*, No.23, 1999, pp.779-804.

[3] V.V. Lysko, et al., New-Generation Coal-Fired Steam Turbine Power Units, *Thermal Engineering*, Vol. 43, No. 7, 1996, 545-552.

[4] Joskow, Paul L., et.al. 1987. "*The Performance of Coal-Burning Electric Generating Units in the United States: 1960–1980*." *Journal of Applied Econometrics*, 2(2), 85-109.

[5] ICRA, 2003, "*Revised report to the Power Finance Corporation of Gujarat Power Sector*", ICRA Ltd., 26, Kasturba Gandhi Marg, New Delhi – 110 001.

[6] MECON Ltd., 2007, "*Report on achievable heat rate and auxiliary power consumption of thermal power stations of MSPGCL*", MECON Ltd., Ranchi – 834002, August 2007.

[7] RTPS, 2008, "*Generation performance of units*", website: http//: www.karnatakapower.com.

[8] DVC, 2005, *"Performance parameters of Thermal Power Plants of DVC for Last Five Years*", website: http//:www.dvcindia.org.

[9] M. Siddhartha Bhatt, R.P. Mandi, S. Jothibasu and N. Rajkumar, "Performance enhancement in coal fired thermal power plants, part IV: Overall system", *International Journal of Energy Research*, No.23, 1999, pp.1239-1266.

[10] Rajashekar P. Mandi and Udaykumar R. Yaragatti, "Enhancing energy efficiency of Induced Draft Fans in Thermal Power Plants", *Proceedings of the Eighth IASTED International Conference Power and Energy Systems (EuroPES 2008)*, June 23-25, 2008 Corfu, Greece, pp. 176 – 182, paper No.608-069.

[11] Ananth P. Chikkatur, Ambuj D. Sagar, "C*leaner Power in India: Towards a Clean-Coal-Technology Roadmap*", Energy

Technology Innovation Policy, John F. Kennedy School of Government, Harward University, Discussion paper 2006-07, Dec. 2007.

[12] Chris Harley, Conforma Clad inc. K. Scott Trunkett, Conforma Clad Inc. "*Improving Plant Performance with Advanced Wear Protection Technologies*", Coal-Ge, August 7, 2003.

[13] Jonathan L. Gomez, "*Modeling of air leakages on a Tri-sector Air heater*", Public Service Indiana, 1987

[14] Rajashekar P. Mandi, R.K. Hegde & S.N. Sinha, 'Performance Enhancement of Cooling Towers in Thermal Power Plants through Energy Conservation', published at "*International conference on POWERTECH 2005*" at St. Petersburg, Russia, Organized by IEEE Power Engineering Society, 27-30 June, 2005. paper No. #461.